Trends in Telephone and Power Practise as Affecting Coordination *

By W. H. HARRISON and A. E. SILVER

The general trends in telephone and electric power systems are outlined and the reactions of certain of these trends on coordination are described.

In the telephone system, brief mention is made of the rapid growth of the dial system of operation, improvements in subscriber-station apparatus, rapid extension of new types of facilities for toll circuits and the growth of connections to foreign countries. Improvements in telephone service increase the importance of securing adequate coordination. The advantages of the use of cable facilities for toll circuits, of repeaters, of carrier current systems as regards coordination of long distance and interurban telephone circuits are discussed. The benefits accruing from improved subscriber-station apparatus, central office equipment, abandonment of iron wire for the short tributary toll circuits and new methods of making sleeves at joints in open wire lines are outlined.

In the power system, brief mention is made of increasing use of larger generating units, and growing use of automatic devices to replace manual operation. Improvements in power service generally react favorably on coordination. The general trends toward higher voltages for transmission and distribution and the improved standards of construction accompanying these trends are described. The important matter of system stability and the practises as regards grounding of transmission circuit neutrals, lightning control and current limiting devices, and the reactions of these matters on coordination are outlined. Reference is also made to grounding of distribution system neutrals, service taps on transmission lines, general practises as regards transformer connections and improvements in wave shape in so far as these matters react on coordination.

In conclusion, it is pointed out that, while there have been influences working both favorably and unfavorably toward coordination, the preponderant trend is definitely toward an improvement. The benefits which have accrued from the activities of the Joint General Committee and the important function of the Joint Subcommittee on Development and Research are also mentioned.

General Trends

THE important benefits resulting from the cooperative handling of questions arising from the proximity of the physical plants of the telephone system and the electric power systems of the United States are emphasized when consideration is given to the extent and the rapid growth of these two industries. This growth is illustrated by Fig. 1 which shows that during the past decade, while the population of the country has increased 16 per cent annual telephone messages have increased 96 per cent and annual kilowatt hour usage of power 107 per cent. Another indication of the growth of these utilities is given by Fig. 2 which shows that during the past decade customers telephone

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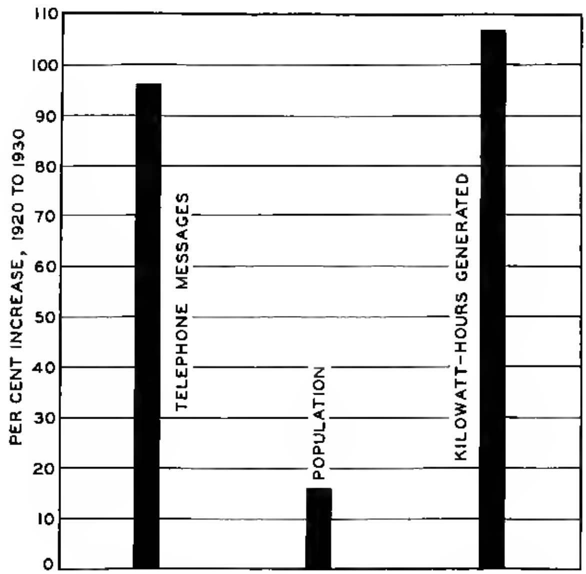
stations have increased 88 per cent and customers of central stations 127 per cent. The leaders of both utilities confidently expect that, apart from temporary setbacks associated with recessions in general business, the recent rapid growth of these utilities will continue throughout the next decade.



1930	Population	123,900,000
	Telephone messages	21,600,000,000
	Kw. hours generated	90,000,000,000

Fig. 1—Per cent increase, 1920 to 1930, in population and in telephone and power usage.

Note: Values for 1930 are estimates based on best available data. Telephone data refer to Bell System.

Such a rapid growth of the two utilities both of which must supply the same customers with services essential to their comfort and prosperity, necessarily brings with it a large number of cases of physical proximity between the plants of the two utilities where, due to the widely different characteristics of the circuits involved, difficulties may arise. The necessity for active study of the coordination of the different systems and for the current handling of large numbers of individual situations will continue for a long time to come.

Associated with this rapid growth there has been another trend in these two utilities which has an important effect on coordination work.

This trend is the steady improvement in the quality of service afforded to their customers.

In the telephone system the improvement in the standards of service, if considered by itself, tends to increase the noticeability and the reaction on service of inductive effects from outside sources. Such changes as the improvement in the characteristics of transmitted speech, including the extension of the band of frequencies efficiently transmitted, and the avoidance of cases in which interfering noises are produced from sources within the telephone plant, tend to increase

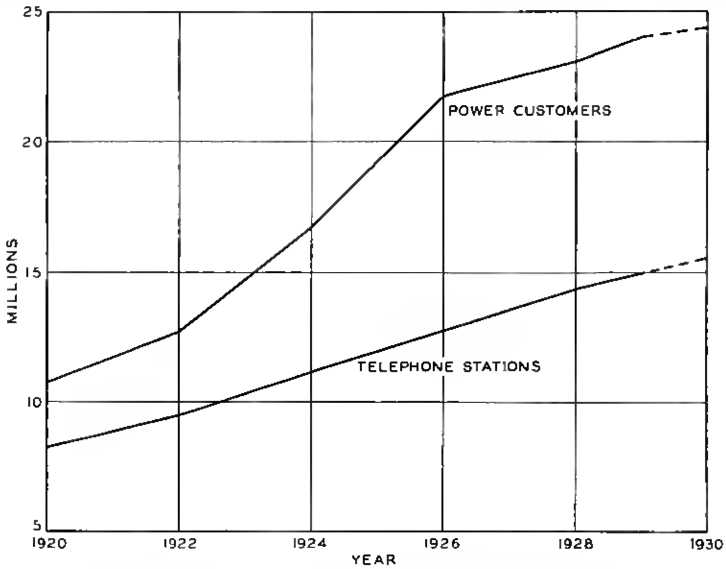


Fig. 2—Telephone station and power customer growth.

Note: Values for 1930 are estimates based on best available data. Telephone data refer to Bell System.

the effect of moderate amounts of noise current induced in the telephone circuits from outside sources. Similarly increases in the extent of the service and in the speed of completing calls have led to increased reliance on prompt telephone communication which tends to increase the importance of avoiding interruptions. Five years ago the average interval of time between the placing of a long-distance toll call by a subscriber and the commencing of the conversation was 7½ minutes. At the present time it is a little less than 2½ minutes. Telephone users have now come to rely on the almost immediate establishment of telephone connections and are correspondingly more critical of interruptions or delays.

The improvement of service has been associated with a particularly rapid growth of very long haul telephone business and a consequent increase in the average length of telephone circuits used for interurban and long distance work. This is illustrated by Fig. 3 which shows the

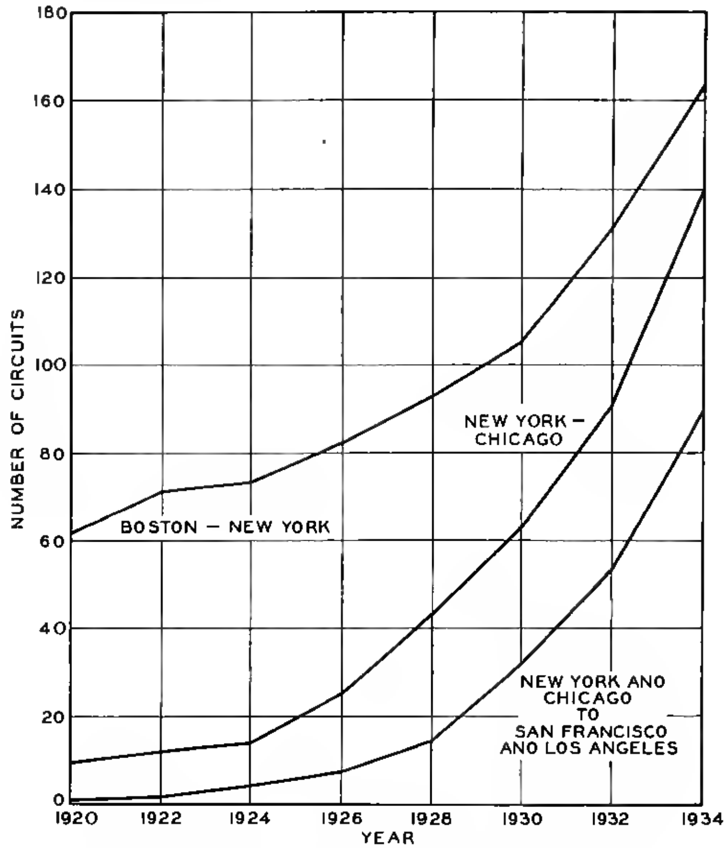


Fig. 3—Long haul telephone circuit growth of typical circuit groups.

growth in the last few years and the expected growth for the next few years of typical circuit groups of different lengths. In the period 1925 to 1929 while telephone toll business as a whole increased 59 per cent New York-Chicago business increased 170 per cent and the combined Chicago and New York business to Los Angeles and San Francisco 380 per cent. From the standpoint of coordination with other electric circuits the very long telephone circuit offers a more difficult problem than the circuit of moderate length because of the cumulative effect of exposures in different sections.

In the power industry one of the most important items in the improvement of service has been the steady decrease in the number of service interruptions. This has been brought about mainly by better standards of construction, including more systematic mechanical and electrical arrangements of circuits and apparatus, and increased numbers of circuits and sources of supply. The interconnection of power systems has figured largely in the last mentioned factor contributing to service reliability, by making available greater numbers of sources and by multiplying the routes over which power can be recieved at specific locations. While the increasing numbers of interconnecting and other types of lines bring new conditions for the coordination of power and telephone plants, improved construction and increased security of circuits and apparatus have a definitely beneficial effect upon matters of coordination by reducing the number of abnormal conditions of operation.

Other items in the improvement of the service given by the power industry are better voltage regulation and a great increase in the number of types of power consuming appliances and apparatus made available for the customer. Accompanying better voltage regulation are certain factors which definitely aid coordination, among these being better balance of currents in the separate phases of the circuits and more effective arrangements minimizing the tendency for currents to flow in the earth. The effect of increased numbers of types of utilization apparatus on coordination is problematical, though probably not of sufficient magnitude to be of practical importance.

Other trends which have a bearing on the improvement of power service are discussed in the section of this paper devoted to the power system.

While in some respects the general trends indicated above, namely, the extent and rapid growth of the two utilities, and the improvement of service standards, have by themselves tended to increase the importance and the difficulties of coordination work, these adverse tendencies have been offset by beneficial effects of improvements in plant design and construction and by the cooperative endeavor which has been carried on by the two utilities during recent years. It is a tribute to the effectiveness of this cooperative work that the degree of satisfactory coordination between the two systems is steadily improving. Fig. 4 shows that during the past 10 years the mileage of telephone toll circuits has increased 250 per cent and the mileage of power transmission lines over 100 per cent. The effect of such growth on the number of situations of proximity is illustrated by the fact that during the past three years the exposures of interest from a noise standpoint have

increased from the equivalent of about 10 miles to about 14½ miles per 100 miles of open-wire telephone toll lead; while on the other hand the exposures not as yet adequately coordinated have in the same period decreased from the equivalent of 2.6 miles to 1.5 miles per 100.

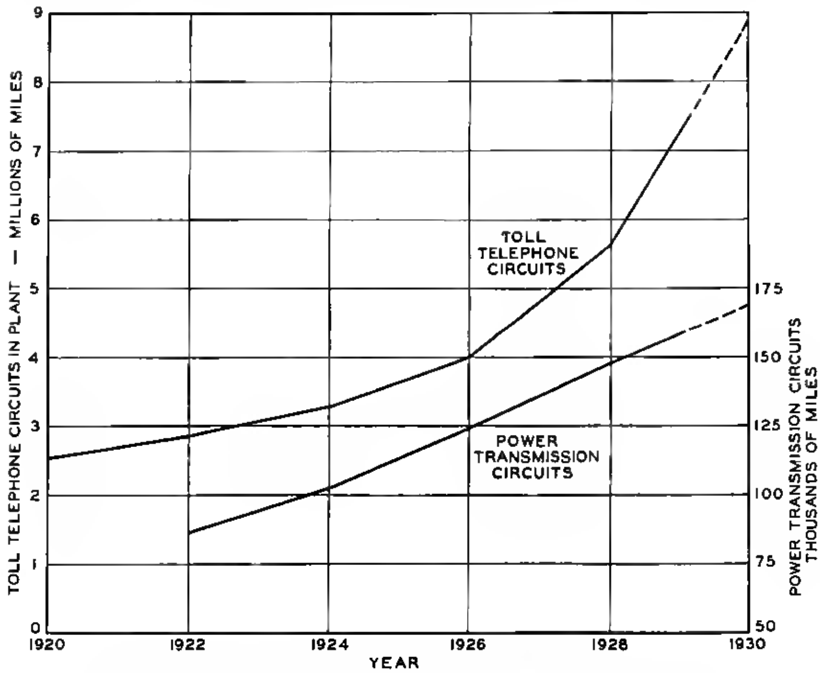


Fig. 4—Toll telephone and power transmission circuit growth.

Note: Values for 1930 are estimates based on best available data. Telephone data refer to Bell System.

While the trends of practise in the design, construction and maintenance of the plants have necessarily been largely controlled by the fundamental requirements of service and economy in developing the two systems, and while the trends naturally have not all been in the same direction as regards their effect on the coordination problem, still the general trend of plant practise at the present time is in the direction to facilitate the coordination of the plants of the two utilities. In the following pages brief statements are made, descriptive of the more important of these trends in the respective systems.

Trends in Telephone System

The telephone plant is at the present time rapidly changing in its physical character through the application of important developments and changes in engineering and construction practise.

Probably the most fundamental and far reaching of these changes is the progress of conversion from manual to dial system operation. When present plans are completed this will result in the operation of approximately 80 per cent of the telephones of the Bell System on a dial basis, and a large part of the existing manual central office equipment will have been removed from service. With the application of the dial system there is a trend toward a greater concentration of central office equipment in one building, so that in the future as many as 100,000 telephones may be switched by the various central office units in a single building. While these trends are of the greatest and most fundamental importance from the standpoint of the development of the telephone business they do not affect the coordination problem in any material way and therefore need not be further discussed here.

An important trend in telephone practise has been the provision of apparatus designed for higher standards of service and greater convenience for use at the customer's station. This includes the hand set, new types of private branch exchanges and of auxiliary telephone station apparatus, and improvements of transmission characteristics. These changes in some respects affect the coordination problem and these effects are indicated below.

Another important fundamental change in the telephone plant and one of great importance from the coordination standpoint is the rapid extension of new types of facilities for toll circuits, that is, long distance and interurban circuits whose use involves what is called a toll charge. These changes and their effects on the coordination problem are discussed in this paper.

One of the most spectacular trends of development of the Bell System at the present time is the increase in the number of connections to foreign countries. Earlier connections to Canada and Cuba were supplemented in 1927 by service to Mexico and by transoceanic radio links providing service from New York to London, through which connection is made to the principal European countries; and in 1930 a similar radio link from New York to Buenos Aires through which connection is made to Montevideo, Uruguay, and Santiago, Chile. During the next few years it is expected that these foreign connections will increase to include generally all important points in South America, Australia, Japan, Honolulu and all other points which may offer an appreciable demand for service.

These intercontinental circuits are not of such character and location as to be directly affected by the physical proximity of power circuits, but their efficiency is affected by the noise currents on connected circuits in the same way as other very long circuits are affected and this is discussed briefly below.

Toll Cable.—The change in methods of designing and constructing toll circuits which is of greatest importance from the standpoint of general development of telephone plant is the great increase in use of cables for those circuits, including both the very long distance circuits and the shorter interurban circuits. This increase is shown by Fig. 5.

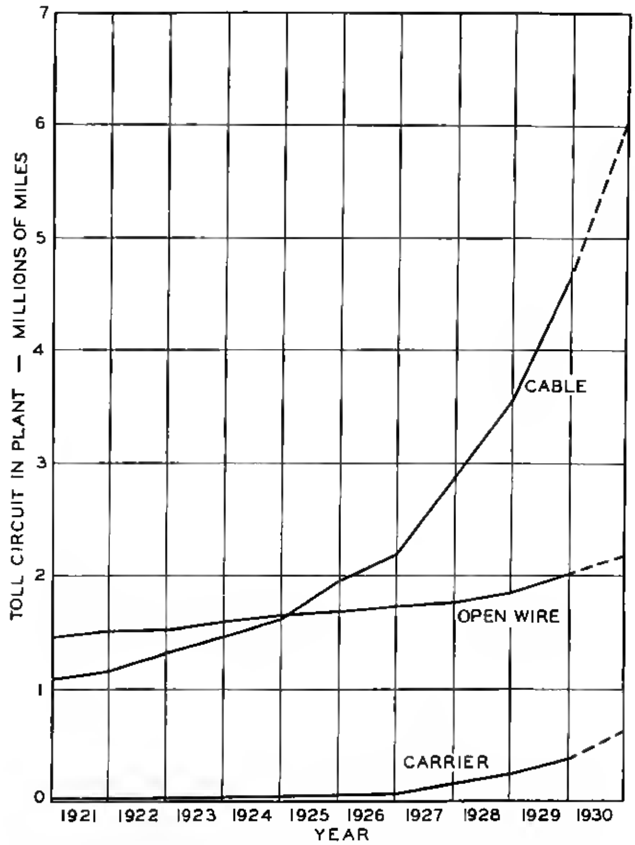


Fig. 5—Toll telephone circuit growth by classifications.

A single cable may provide for from 250 to 500 telephone circuits and several hundred telegraph circuits, that is, as many circuits as would be provided by five to ten heavily loaded pole lines of aerial wire construction. This concentration of circuits in a single cable, a number of which can be placed on a single route, is in itself of great assistance in coordination problems by greatly reducing the number of routes for which coordination arrangement must be made. Furthermore, the

presence of the lead sheath, together with the twisting of the cable conductors, the high degree of balance with respect to ground, and the mutual shielding effect of the many circuits in one cable, practically prevents noise currents from being induced directly into the cable circuits from outside electrical sources. The shielding effect of the lead sheath when suitably grounded also provides substantial reductions in the voltages of fundamental frequency which may be induced along the cable conductors at times of trouble on neighboring power systems.

A telephone toll cable with its associated equipment costs about the same per mile as a twin circuit power transmission line of the 110-kv. class. This high cost has led to a large use of private right of way for new extensions of these cables, particularly for aerial cable construction. This, of course, has an added advantage from the coordination standpoint in tending to keep these important telephone routes off the highways, which are so much used for the distribution systems of both utilities. In the more rapidly growing cable routes underground conduit construction is employed and these in most cases are located along the highways. In these cases, however, the close proximity of several cables in the same conduit run offers a considerable amount of mutual shielding effect which reduces the susceptiveness of circuits in these cables to values approaching that obtainable by a single tape armored cable.

This tape armored cable, which recently has been placed in use in this country, is designed for burying directly in the ground, and has an increased degree of magnetic shielding. This is provided by two wrappings of steel tape outside the lead sheath which are necessary for the mechanical protection of the cable when ducts are not used. During the past year about 160 miles of this cable were installed and it is expected to have a considerable field of use in the future.

As indicated above, in all these types of cable construction the susceptiveness to noise induction is so greatly reduced that low frequency induction generally becomes the limiting factor relative to the permissible proximity of these cables to power circuits. The relative amounts of induced voltages with these different types of construction in comparison with open wire construction, while naturally varying with local conditions, are indicated in a general way in Table I.

TABLE I

Type of Construction	Approximate Relative Volts on Telephone Circuits per Ampere of Inducing Current at 60 Cycles
Open wire	1.0
Single cable, aerial or underground—sheath well grounded	0.5
Buried tape armored cable—well grounded	0.2

Note: All values for cables assume full size, i.e., 2⅝-in. diameter.

The above figures are based on favorable conditions for obtaining low resistance ground connections on the cable sheaths. Such ground connections are necessary to provide the full shielding benefits, since the shielding is brought about by induced currents on the cable sheath flowing along the sheath and through ground. These sheath currents, because of the close coupling between the sheath and pairs, induce voltages into the pairs tending to neutralize the voltages induced into the pairs directly from the power system. The use of the tape armor, which is a magnetic material, increases the coupling between the sheath and pairs. The grounding conditions necessary for satisfactory shielding effects can usually be obtained, but situations sometimes arise in the case of aerial construction where it is difficult or impossible to obtain them.

While as noted above, the cable circuits are effectively protected from noise induction, the efficiency obtainable over the long circuits is limited in part by the noise currents occurring in the open-wire lines which may be switched to the long cable circuits. This is because the efficiency of the long cable circuits depends upon voice-operated switching devices which must not be operated by the noise currents. This is also true of the intercontinental circuits mentioned above. The extension of the circuits controlled by voice-operated devices tends therefore to increase the importance of good coordination of the entire plant.

Telephone Repeaters.—Another important trend of practise is the extended use of telephone repeaters. The purpose of these devices is to amplify the voice currents and thus make possible higher efficiency and greater extension of long distance telephone circuits. Their use is essential to the great development of toll cable. Moreover, they are used widely on open-wire circuits. Without repeaters it was necessary on the long open wire circuits to permit the power level of voice currents to sink to relatively low values. An extreme example of this is given by the New York-Denver circuit which, before repeaters were available for use on this circuit, had an overall equivalent, using the highest grade of telephone construction which had been developed up to that time, of about 31 *db.*[1] With the application of repeaters to this circuit the level of voice currents could be kept relatively high throughout the circuit. This is illustrated in Fig. 6 giving level diagrams for the circuit as originally set up and later when provided with repeaters.

The use of repeaters contributes to reducing the susceptiveness of the telephone plant and thus aids coordination. On such a circuit as the original New York-Denver circuit just mentioned, a relatively

[1] This means that the ratio of output power to input power of this circuit is 0.0008.

small amount of noise current greatly impaired transmission because of the weak incoming voice currents. Although the repeaters naturally amplify the noise currents as well as the voice currents, the fact that the voice level is kept high throughout results in great benefit which in this case, assuming similar exposure conditions in the various repeater sections, gives an improvement in the ratio of voice currents to noise currents of slightly over five.

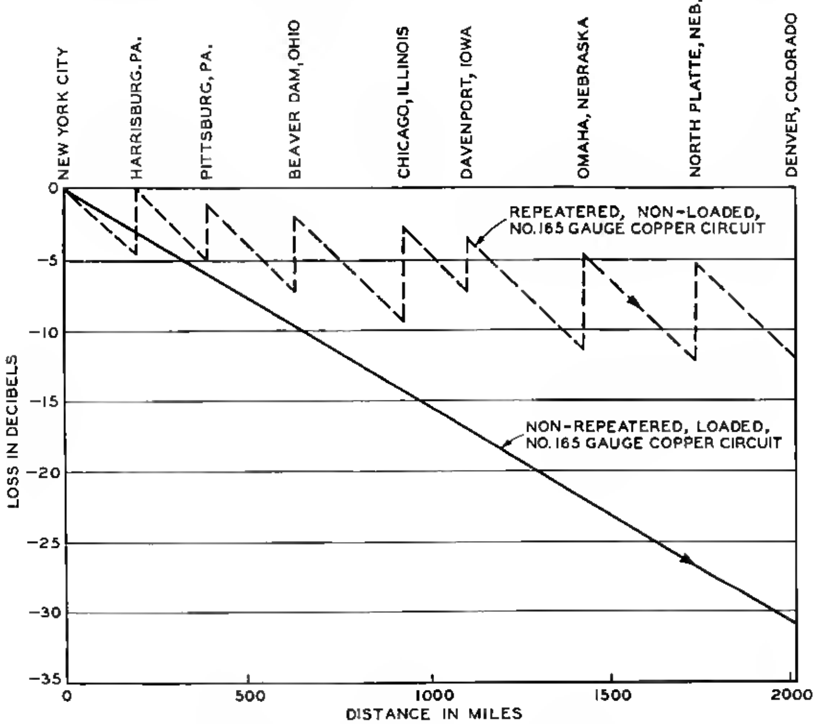
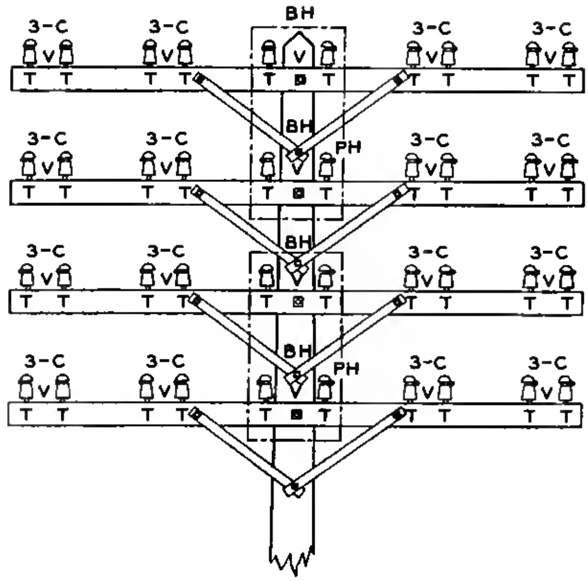


Fig. 6—New York—Denver circuit level diagrams.

Repeaters probably also have some effect in reducing certain of the effects of low frequency induction by the fact that they sectionalize cable lines at about 50 mile intervals and open-wire lines at intervals of 200 miles or less, and limit the power which can be transmitted from section to section. There is some evidence that this tends to limit acoustic shocks.

Carrier Telephone Systems.—A third important trend in telephone practise is the extension in the use of carrier telephone systems for long circuits and the associated changes in aerial wire construction practises. The growth in use of this type of circuit is indicated in

Fig. 5. The carrier systems are much less influenced by noise induction from power circuits because they occupy a range of frequencies (5000 to 30,000 cycles) in which the harmonic power voltages or currents ordinarily are extremely small. Furthermore, in order to obtain economies inherent in the use of large numbers of carrier systems on the same telephone pole line it has been necessary to design systems of



LEGEND

SYMBOL	FACILITY	TOTAL CIRCUITS	
V	VOICE FREQUENCY-PHYSICAL	20	
PH	VOICE FREQUENCY-PHANTOM	2	
3-C	CARRIER TELEPHONE	48	
T	D-C TELEGRAPH	40	
BH	CARRIER TELEGRAPH (10 CHANNELS)	40	
	TOTAL TELEPHONE		70
	TOTAL TELEGRAPH		80

Fig. 7—Pole line configuration.
Non-phantomed construction—8-inch spacing between wires of non-pole pairs.

transpositions of much increased effectiveness and even to change the configuration of the wires in order to greatly reduce the inductive effects between the telephone circuits. These changes also result in reduced susceptiveness to outside inductive influences. The type of construction now recommended for new aerial wire lines in cases where the extensive use of carrier is anticipated is shown in Fig. 7. The two wires of each pair, except pole pairs, are spaced 8 in. apart compared

with the previous standard of 12 in. Often transpositions are made as frequently as every second pole and are of an improved type giving better balance between circuits; also on the circuits on which carrier telephone is used the phantoms are abandoned. The relative susceptiveness to noise frequency induction of the various types of aerial wire construction has been tested for various typical conditions. The results of these investigations are summarized in Table II.

TABLE II

Facility	Type of Transposition *	Approximate Relative Susceptiveness †
12 in. phantom	Voice (brackets)	1.00
12 in. side	Voice (brackets)	0.50
8 in. pair	Carrier (break irons)	0.25 or less

* Voice circuits are not so frequently transposed as carrier circuits. Bracket type transpositions require two spans to complete the transposing whereas the break iron type completes the transposing on a single crossarm.

† Susceptiveness is used in the sense defined by the Joint General Committee, namely, "Those characteristics of a signal circuit with its associated apparatus which determine, so far as such characteristics can determine, the extent to which it is capable of being adversely affected in giving service, by a given inductive field."

Subscribers' Station Apparatus.—To a large extent the trend of development in subscribers' station apparatus is toward new arrangements which provide greater convenience and more closely meet the needs of the users and which have no material effect upon the coordination problem. An important group of developments, however, centers about the improvement of the electrical performance of the station apparatus by removing impairments caused by the earlier types of apparatus. These changes, by improving the quality of speech as reproduced by the telephone system, tend to make more noticeable the impairments caused by the effects of currents induced from external sources.

The tendency toward an increase in the range of voice frequencies efficiently reproduced by the telephone system tends to increase the range of frequencies of induced currents which may cause noise interference as discussed in the introductory section. An extreme illustration of this is the circuits designed to transmit programs for radio broadcasting stations. The transmission characteristics of these circuits have been improved by including both higher and lower frequencies, and in their most modern form these circuits efficiently transmit currents of frequencies in the range between 35 cycles and 8000 cycles and are therefore capable of being affected by inductive noises over this wide range.

The room noise conditions at the subscribers' premises have an effect on telephone transmission. This noise besides acting directly on the

ears of the telephone user is converted by the transmitter into electrical currents, a part of which actuates the receiver, thus producing noise. The present trend in telephone practise is very strongly toward a reduction of these effects. This will tend to bring into increasing prominence noise caused by induction in the telephone circuits which now in many cases is partially overshadowed by the reproduction of the noises in the room.

As partly offsetting this tendency steps have been taken to improve the degree of balance to ground of new station apparatus, particularly in the case of party lines. The new station apparatus with the improved transmission characteristics discussed above will be designed for reduced effect of noise currents entering from the line. Also, in extending the selective signaling features to rural areas, higher impedance ringers and a newly developed high impedance relay are being used in order to limit susceptiveness to noise from exposures between the rural open wire extensions and rural power distribution circuits. Where central office equipment is being modified to permit of increased range of direct current signaling, or for some other reason, the reduction of susceptiveness is always a consideration. All of the newer repeating coils used for supplying talking battery to subscribers in common battery areas, which comprise the bulk of the local plant, possess a much higher degree of balance than the coils which were standard a few years ago.

Other Items.—So far the changes which are associated directly with the major trends of development in the telephone plant have been described. The broad outlines of these developments depend on all of the factors affecting telephone service as well as coordination with power circuits. There are other features not directly associated with these main trends which, while introduced into the telephone plant largely because of the advantages to be gained in reducing susceptiveness to electrical influences, have also afforded other benefits. A few of the more interesting examples of these changes are given below.

Referring to the toll plant, there may be mentioned the recently adopted general practise of soldering aerial wire sleeve connections in order to insure a permanently high degree of series balance. Heretofore reliance had been placed on the contact between the wires and the twisted sleeve. The practise of soldering will be supplemented in the near future by a cold-rolled sleeve method, and it is confidently expected that these practises will result in material noise improvements. They will also probably reduce the maintenance required on open wire toll circuits, particularly where exposures are involved.

Another item is the abandonment of the use of iron wire and sub-

stitution of copper for short tributary toll circuits. Coordination of the iron wire circuits is relatively difficult because of the development of resistance unbalances at the wire joints. The transmission efficiency is also improved by the reduced resistance afforded by the copper but this effect is generally of secondary importance in the short tributary circuits.

In toll offices improvements have been made in the balance of coils and condensers used for superposing telegraph on the telephone circuits. The use of repeating coils, commonly used for side-circuits, has been extended to phantom toll circuits. These coils act as insulating transformers to prevent noise voltages from the outside conductors being impressed upon the intricate cabling and equipment of the office.

Referring to the local plant, there are several noteworthy examples of modifications made principally for the purpose of reducing susceptiveness. Investigation such as that of the coordination between power and telephone distribution plants conducted at Minneapolis by the Joint General Committee, stimulated the development of means for reducing the susceptiveness of the telephone distribution plant. Present practises call for the interconnection of aerial and underground cable sheaths and the grounding of the aerial sheath in order that the benefits of the shielding action of the sheath currents as previously described, may be realized for noise induction. In cases where electrolysis conditions do not permit direct grounding, condensers of the electrolytic type are employed to prevent the flow of direct currents.

The telephone circuits have long been equipped with over-voltage protectors for the purpose of protecting apparatus and cables against lightning waves and against power frequency transients from the lower voltage distribution circuits, also with fuses for opening the lines in cases in which heavy currents flow. The trend in development of these devices has been principally toward more uniform operation and lower maintenance costs. With the rapid increase of voltage and capacity of power circuits generally, experimental studies have been undertaken of further means for maintaining the safety of persons working on or listening on the telephone circuits. At the present time, development work is being done on various devices for this purpose, some of which are fundamentally different in design and operation from those previously used. It is hoped that these devices, which are discussed in one of the following papers, will afford increased protection against overvoltages and improve coordination conditions.

Trends in Power System

In the field of power generation marked attention has been paid, from the start, to methods of improving the efficiency of the generating

process and reducing the investment per kilowatt of generating capacity. This has led to the development of larger and larger generating units. A single shaft unit of 160,000 kw. capacity and a triple-element unit of 208,000 kw. capacity are in operation. The latter consists of one high pressure and two low pressure turbincs with their respective generators. Single shaft units of 200,000 kw. capacity are under construction and it seems probable that the trend in the future will be toward even larger units of both types. This trend toward larger units instead of the equivalent in small units has resulted in improved wave shape but otherwise does not directly affect coordination except in so far as it may reflect the general trend toward larger concentrations of power with the accompanying tendency to increased magnitude of system abnormals.

Another definite trend in the power industry, but one which is not of importance from the standpoint of coordination, is the increasing use of automatic devices to replace manual operation. Complete automatic operation is being practised to some extent in hydroelectric generating stations and is widely practised in substations of various types. The trend is definitely toward wider use of automatic devices and new types and applications of such devices are being constantly developed.

In view of the remarkable development and rapidly multiplying uses of thermionic tubes and related devices in other fields, and the theoretically potential applications in the power art, the question will doubtless be asked as to the trend of their application in the power field. However, other than application for current rectification, such as in railway work, it cannot be said that progress has advanced to the point of establishing a trend.

Those trends in power system development which are more directly concerned with matters of coordination are discussed in the following.

System Voltages.—Referring to Table III, it is of interest to note that the rate of increase of transmission line mileage, as a whole, is lagging behind the rate of growth of both installed generator capacity and electricity production. Furthermore, mileages of the higher transmission voltages, 220 kv., 132 kv., 110 kv. and particularly 66 kv., are growing at a faster rate than the group average. These comparisons reflect the increasing utilization of the higher voltages with the greater circuit capacities they provide. As power industry growth requires the handling of larger blocks of power and as greater distances between sources and markets are encountered, the development and use of circuits and apparatus to transmit at voltages higher than the 220 kv. initiated in 1923 must be expected as an economic necessity.

In the distribution field also, coincident with the development of rural service, there has been a movement to higher voltages in primary circuits, and indications point to the continuance of this trend in the future. Due to the distances involved, voltages from 6600 to 13,200 (and even higher) have been used in rural work. In urban areas the high load densities encountered in some districts require the handling of large blocks of power in the primary circuits, and the lower primary voltages have often been replaced by higher voltages for such conditions. In addition to the greater capacities provided by the higher voltages, possibilities of system simplification by combining rural and urban systems and eliminating voltage transformations are of considerable economic importance.

While at first glance the pronounced trend to higher transmission and primary distribution voltages may appear to enhance the difficulties of coordinating communication and power lines, certain factors enter to offset this. As transmission voltages increase, line construction as a whole becomes more massive, greater clearances and wider rights of way become necessary and construction costs per mile rapidly rise. These greater space requirements weigh against the use of highway locations and, together with the higher construction costs, which make the shortest possible lengths desirable from an economic viewpoint, frequently influence the selection of direct cross-country private rights of way providing generally greater separation from communication circuits in the same territory.

TABLE 111

Total Circuit Miles of Transmission Lines. By Voltages, Years 1926–1929 Inclusive

Voltages	1926	1927	1928	1929	Per Cent of Total 1929	Average Annual Increase Per Cent 1926–1929
220,000	1,054	1,257	1,442	1,442	0.9	11.0
132,000	3,125	3,343	4,010	4,448	2.8	12.5
110,000	7,875	8,661	9,114	10,159	6.4	8.9
66,000	12,157	15,212	18,716	21,236	13.3	20.4
60,000	8,801	9,257	8,076	8,174	5.1	−2.4
44,000	7,517	8,492	8,732	8,761	5.5	5.2
33,000	23,831	24,706	27,451	28,523	17.9	6.2
22,000	10,130	10,429	11,545	12,583	7.9	7.5
13,200	19,496*	18,441*	19,551	21,340	13.4	3.1*
11,000	8,072	9,145	10,007	10,860	6.8	10.4
All other over 11,000	28,223	28,535	29,843	31,916	20.0	4.2
Total	130,281	137,478	148,487	159,442	100.0	7.0

* This apparent discrepancy is believed to be due to reclassification of these lines as between transmission and distribution facilities.

The use of the higher voltage circuits, each transmitting many thousands of kilowatts, of itself tends to increase the problems of coordination. However, the greater separations obtained by the use of private rights of way for these main transmission circuits in most cases eliminate the need for coordinative measures to control normal induction (manifested as noise in the telephone circuits) and, in case noise presents a specific problem, the greater separations simplify and render less extensive those specific coordinative measures which may be required. Induction due to power system abnormals too is mitigated or rendered easier of control.

In the case of distribution lines, the adoption of increasingly higher voltages is accompanied by more systematic grades of construction and greater clearances from communication circuits. The result, of course, is that fewer abnormal conditions of operation occur and the number of related disturbances in the communication circuits is correspondingly reduced. The possibility of contact between power and communication circuits is also reduced. This trend toward better grades of construction applies also to transmission lines and, as noted previously, to other parts of the power system.

System Stability.—During recent years considerable attention has been paid to the development of methods for improving system electrical stability. One of the most important of these methods is the use of higher speed switching,—at present, faults can be cleared in 15 cycles, or less, of a 60 cycle wave. So far, high speed switching has been applied mainly to transmission circuits. However, as development proceeds and cost of equipment required is reduced, the field of application of high speed switching may naturally be extended to distribution systems. The result in the case of either transmission or distribution will be, of course, to reduce the duration of transients. Akin to high speed switching, the use of high speed excitation of rotating equipment has been developed. This may tend to increase the maximum fault current values somewhat which would make coordination more difficult. However, the reduction in the severity of instability surges, in so far as such surges involve faults-to-ground, affords definite benefits from the coordination standpoint. It requires further study and observations to determine what, if any, inherent limitations or advantages it may possess with respect to coordination work.

The way has been paved for the development of high speed switching by steady improvement in relaying practise. Selective operation of protective relays in power systems, during the early stages of relay development, was largely dependent upon an additive sequence of time intervals which might aggregate a considerable period in the case of the

more remote units in the sequence. The development of relaying practise has included various methods of securing selectivity independently of time. This has accomplished large increases in the over-all speed of operation, at the same time improving selectivity. Coincident with these improvements there has also been a substantial gain through greater precision in design and workmanship and improved application of relays and related devices. These trends definitely aid coordination by reducing duration of transients, eliminating faulty relay operation, and steadily reducing the radius of influence of system abnormals.

With the growth in power systems and major interconnections, the use of bus or feeder current limiting reactors or other means of limiting the concentration of fault current flow is being given increasing application. Such practise acts to restrict the magnitude of inductive transients. In distribution systems the growing use of feeder reactors has a similar effect in matters of coordination.

For well known reasons, among which are the avoidance of transient over-voltages resulting from arcing grounds and the economies made possible in apparatus insulation, it is predominant practise in America to ground the neutrals of transmission systems at important transforming centers, sometimes through resistors or reactors but usually solidly. In view of the prevalence of the latter method, a large proportion of higher voltage transformers now in service have been constructed with insulation between the neutral ends of the grounded windings and the core and tank, designed to support only the neutral potentials produced by fault currents regulating through the unavoidable impedance of grounding connections. The economies resulting from this method of construction become greater as rated operating voltages rise. The use of solidly grounded neutrals tends to make coordination more difficult in view of the possibilities for increased flow of earth currents.

On some large power networks with relatively great possible concentrations of short-circuit power and solidly grounded neutrals tendencies towards instability of operation have appeared. In some instances also oil circuit breaker characteristics, particularly as regards the older breakers in service, have become a source of concern. For these reasons, in these situations, increasing study and consideration are being given to the use of current limiting devices in the neutral where the characteristics of the apparatus and limitations of relaying will permit of such operation.

In some European countries, particularly in Germany, where grounding for the purpose of power system voltage stabilization is excluded

by governmental regulation, dependence is extensively placed on the Petersen coil as a substitute. This device may be regarded as a special type of neutral impedance. The Petersen coil has been applied to but limited extent in this country although its possibilities for moderate voltage systems, especially for situations warranting only single circuit supply, are receiving consideration.

In this country, the increasing use of neutral impedance as well as the use of other types of current limiting devices is an aid to coordination since it reduces the magnitude of abnormal induction.

Lightning Control.—The major problem of the transmission art at the present time is the control of lightning in its effects on service. In those sections of the country in which lightning is prevalent, this natural hazard accounts for a large proportion of transmission circuit faults, approaching 100 per cent in the case of the heavier, higher class trunk transmission lines. The seriousness of this problem and the researches which some of the larger power utilities and apparatus manufacturers are conducting for its solution are being fully reported from time to time before the Institute and need not be discussed here. It is sufficient to say there is encouragement that methods for the solution of this problem, as it affects high voltage trunk circuits, will be known in the not too distant future. Where adequate methods are found and applied the results, of course, will be a decrease in the number of system disturbances which induce transients in communication circuits.

Present measures in power system practise, especially at the higher voltages, directed toward the control of service interruptions caused by lightning include improved application of overhead ground wires, improved grounding connections at the supporting structures, the improved use of wood for lightning insulation, and the use in shunt with line insulators of fused gaps or other valve devices to "spill" the surge without dynamic current follow up. There is also under consideration the application on grounded neutral systems of single-phase switching. All of these measures, with the exception of the last, are helpful from the coordination viewpoint since their effect is to avoid or reduce system faults or at least to decrease the magnitude of earth fault currents and hence of the accompanying voltages induced in nearby communication circuits.

Single-phase switching involves the use of individually controlled and operated single-phase circuit breakers. Upon the occurrence of a single-phase fault-to-ground, the breakers on the faulty phase only would open, leaving the other two-phase conductors in circuit to maintain connection momentarily between source and load. In a short

interval the breakers controlling the faulty phase would be reclosed automatically.

Single-phase switching has not progressed beyond a preliminary consideration of its possibilities. If applied in situations of proximity, the residual voltages and load currents while one phase of a three-phase grounded neutral system is momentarily open circuited may constitute a problem in coordination.

Underground Construction.—The use of underground construction in distribution systems is seldom economical but is increasing in high load density districts and in some residential areas primarily due to requirements for civic improvements and the relieving of surface congestion. The reduced influence on communication circuits of such underground circuits as compared to overhead construction, is too well known to need repeating here. Coincident with the more recent developments in underground distribution certain special situations have brought about the development of underground cable suitable for use in high-voltage transmission circuits, inclusive of 132 kv. Underground installations involving these transmission voltages are highly special, comparatively few in number and small in extent. However, they have a definitely favorable effect upon coordination problems withing the territories surrounding them.

Aerial cable construction for both distribution and transmission circuits has been used to a limited extent and has a definitely beneficial effect upon coordination matters. Whether this type of construction will be extended in the future is not evident.

Grounding of Distribution System Neutrals.—One of the difficult tasks encountered in distribution systems is that of obtaining adequate grounding of primary and secondary circuits. Because of this difficulty the establishment of neutral networks grounded at many points has become a practise. In most cases in the past, two separate neutral networks have been provided, one for the primary and one for the secondary system. However, in several localities these two separate neutrals have been combined into a common-neutral arrangement providing in this way an increased multiplicity of ground connections to both the primary and secondary neutral conductors. Further extension of the use of this system is probable. This arrangement introduces features of interest from the coordination standpoint, because of the increased opportunities for the flow of currents through the ground. Experience and investigations so far, however, indicate that with adequate attention to coordination this arrangement is comparable in its effect on neighboring communication circuits, to other types of distribution systems.

Service Taps on Transmission Lines.—In some rural situations, it has been found economically impracticable to initiate distribution lines due to distances involved. However, in many such situations immediate electric service is urgently required and in some of these cases, transmission lines may be located relatively close to the point where service is desired. In such cases the only alternative to a long distribution line is to tap the high tension transmission line when this can be done by some less expensive method. Such methods have been developed and applied to a limited extent. More study and field experience are needed to determine the effects of these installations on inductive coordination should they become extensively employed.

Transformer Connections.—In distribution practise, the trend toward higher primary voltages has been accompanied by the use of the "Y" connection of the primaries of transformers as a step in the transition from one voltage class to another. Thus 2300-volt delta systems have become 2300/4000-volt "Y"connected systems, 6600-volt delta systems have become 11,000-volt "Y" systems, and the 7620/13,200-volt "Y" connection is being used. The use of the "Y" connection of the primary of distribution transformer banks is sometimes necessarily accompanied by a similar connection of the secondary. Such "YY" connections are usually in urban situations. Also, these banks usually represent only a small portion of the total transformer capacity on the circuits.

On large transformer banks and in the higher voltages delta-Y connections have long been the prevailing practise. However, where the "YY" connection is used for purposes of grounding, especial attention has been given to controlling the effects of this connection in situations of coordination, and for the absorption of triple harmonic currents it is common practise to use delta-connected tertiary windings in such installations. This subject is discussed more fully in another paper in this symposium.

Wave Shape.—The connection of primary circuits directly to generating station busses results in service and economic advantages by eliminating transformations thereby improving voltage regulation and aiding system simplification. This practise, however, tends to make coordination more difficult as those harmonics which may be present in the generated voltage can flow directly out over these circuits. However, the important bearing of the wave shape of generators and apparatus of various kinds on the coordination problem has long been realized and is receiving increasing attention. Even before the formation of the Joint General Committee the general problem of apparatus wave shape was being studied both as to the amounts of various har-

monic components which were present in apparatus wave shape and as to the relative effect of these components when appearing in communication circuits by induction from power circuits. As a result of this study an instrument was developed for measuring "Telephone Interference Factor" of a voltage wave. With this instrument as an aid a better understanding of the bearing of wave shape has been gained by the apparatus manufacturers and there has resulted a gradual improvement in the wave shape of new apparatus.

It is recognized that there is a median line beyond which general improvement in the inherent wave shape of apparatus would not justify the attendant increased difficulties of design and increased manufacturing costs,—to avoid the alternative of applying in specific cases, available and less expensive methods of externally correcting wave shape. Work is now in progress cooperatively between the manufacturers and users looking toward the establishing of a measure of wave shape in apparatus design which will strike an economic balance between benefits and burdens.

The increasing use of rectifiers for conversion from alternating to direct current has an influence on inductive coordination. Considerable study has been devoted to this matter as result of which methods for control of the distortion of the d-c. voltage wave caused by the rectifiers have been applied in several instances and a solution of this part of the problem appears to be in hand. More study and experience are needed as regards the specific conditions under which the wave shape distortion of the alternating current supply would require consideration.

With the progress begin accomplished in the design and application of apparatus and the better understanding of the influence of circuit and transformer connections on inductive relations, problems concerned with wave shape can be expected to steadily decrease. The status of the cooperative study of this subject is described in this symposium.

Conclusion

A brief outline has been given here of the general trends in plant development and operating practise in telephone and power systems with special regard to those trends which affect the problem of coordination. While naturally there have been influences working favorably and others working unfavorably toward the problem it is clear that the preponderant effect of the development now being applied in the two industries is reducing the proportion of new situations in which specific coordinative measures are necessary. While to a considerable extent, as indicated in the body of the paper, this is due to the natural trends

of plant design associated with new developments within each of the industries, it is also true that the extent of the progress made is due in no small measure to the careful study of all phases of the problem being conducted by the Joint Committee of the National Electric Light Association and the Bell Telephone System.

Under the guidance of this Committee and soon after its formation, the types of situations of physical proximity were classified and certain broad principles of cooperation were recommended. Soon thereafter more complete principles and detailed practises were formulated. These principles and practises were printed and widely distributed to companies and individuals directly interested in the problem of coordination.

The principles and practises thus set up were largely qualitative and the need for an organized program of research to establish quantitative data and to develop improved physical facilities for coordination was early recognized. Accordingly, the Joint Sub-committee on Development and Research was organized, and assigned the work of determining both experimentally and by field experience quantitative data covering the various aspects of coordination problems, and of developing detailed methods of effecting physical coordination. Under this Sub-committee a very large volume of research work has been undertaken. Results of some of this work have been published and a considerable amount is now in progress. The three papers to follow in the symposium discuss much more fully three of the most important aspects of coordination work at the present time and tell of the work being done in these fields by the Joint Sub-committee on Development and Research and by the other branches of the Joint General Committee's organization.

In reviewing this subject one is impressed by the number of ways in which the coordination problem touches both the telephone and power fields, and by the very large amount of cooperative work which has already been done. This work, as has been indicated, has resulted in great progress in the satisfactory handling of coordination matters of all types. This matter concerns two industries both of which are in a period of rapid development and change, both as regards their size and as regards the physical arrangements which constitute their plants. Many new developments in each plant require consideration from the standpoint of coordination. It is evident, therefore, that if the ground already gained is to be held and further progress made, the channels of cooperation between the two industries must be kept in operation

both for the consideration of new problems arising with new developments in the industries, as well as for the further perfection of the cooperative methods of handling specific problems. These papers in other words do not constitute in any sense a final report. They are intended to show the present status of two very active and rapidly changing arts and to indicate the highly satisfactory results which have followed from a number of years of sincere cooperative effort between the telephone and power industries.